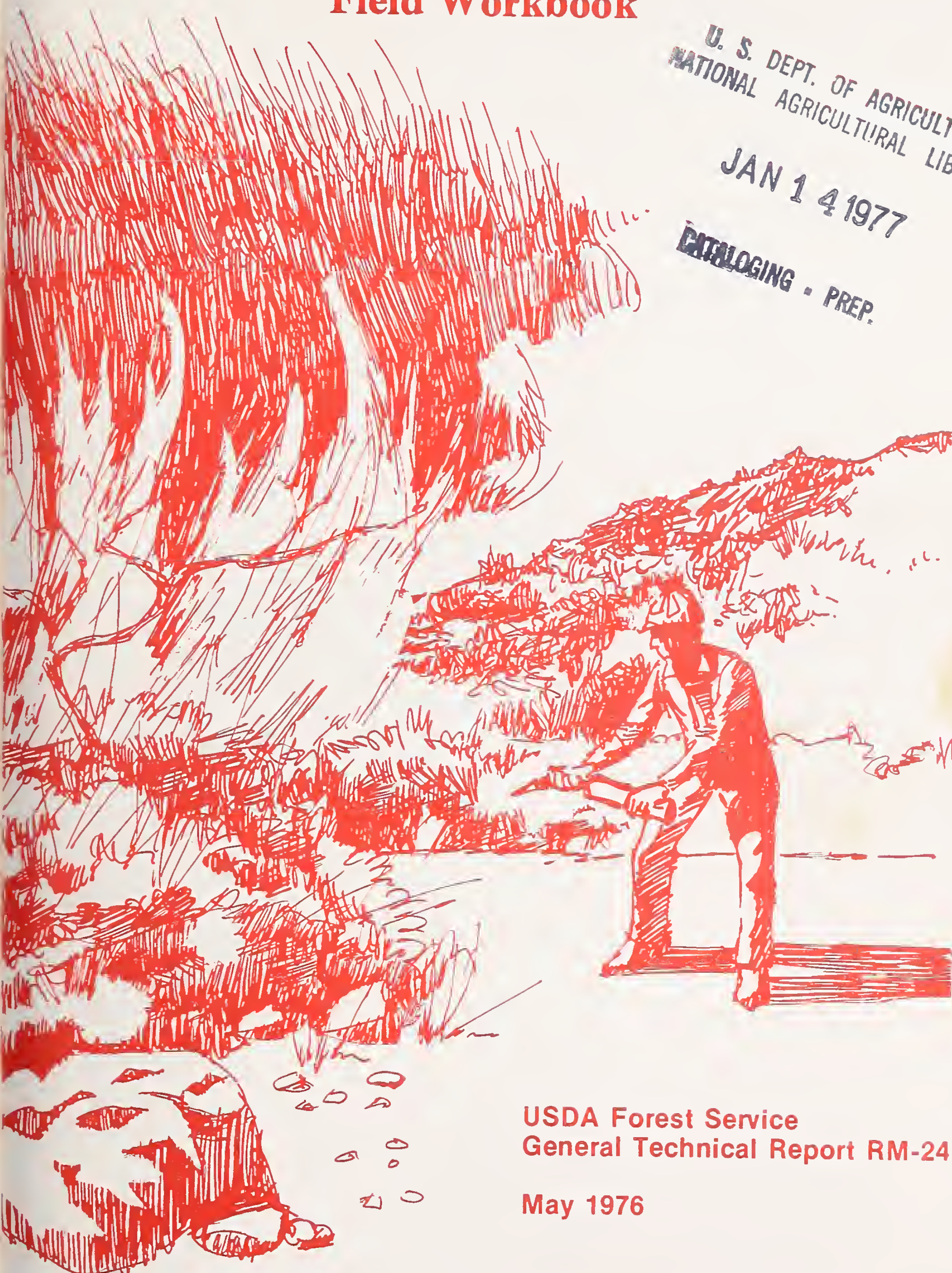
PREDICTING RATE OF FIRE SPREAD (ROS) IN ARIZONA OAK CHAPARRAL: Field Workbook



USDA Forest Service
General Technical Report RM-24

May 1976

Rocky Mountain Forest and
Range Experiment Station
Forest Service
U.S. Department of Agriculture
Fort Collins, Colorado 80521

Abstract

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PREDICTING RATE OF FIRE SPREAD (ROS) IN ARIZONA OAK CHAPARRAL: Field Workbook

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Contents

Introduction

Predicting fire behavior is a difficult task. Long-distance spotting, development of fire whirls, and simultaneous ignition over large areas are fire behavior characteristics that are difficult to forecast with accuracy, and can be predicted only in a very general way. It is important, however, that the fire manager be able to predict rate-of-fire spread (ROS) in order to manage all types of fire more effectively. Research Paper RM-101 "Predicting fire spread in Arizona's oak chaparral" by Lindenmuth and Davis (1973) presents the results of research designed to provide improved estimates of rate-of-fire spread in the Arizona oak chaparral. It describes the predictive fire spread model in detail, but is not intended to be a manual for use in the field.

The purpose of this field workbook is to put these research findings into a form that can be more readily utilized by the fire manager. The model, or formula, in this workbook can be used for predicting ROS on wildfires; it has an equally important role in predicting ROS for prescribed burning. The model was developed by burning a number of experimental fires, and has been tested on a number of wildfires. For user convenience, the ROS formula is set up in a worksheet form (see inside back cover). Thus the user determines certain values in the field, records them on the worksheet, and (after appropriate transformations) calculates the predicted ROS.

It is not always easy to verify ROS predictions in the field; thus the ROS figures must be considered as *indicators* or *guides*—just as the Burning Index or Fire Load Index are considered as guides in predicting burning conditions or manpower requirements. Even with these guides, considerable judgment is needed in applying the predicted values. In spite of these uncertainties, however, the fire manager *should* be able to relate the predicted ROS to the fire behavior he observes on the fire. Knowing the ROS value, and tempering this information with experience gained in watching fires burn, the fire manager can fairly accurately relate fire spread to the predicted value, and thereby control and apply fire more safely and effectively.

Ground Rules

The following qualifying statements are presented to help clarify some of the basic assumptions that were considered, or omitted, in developing the predictive model. These statements do not necessarily detract from the accuracy of the model—they indicate the model must be used with a certain amount of good judgment.

- Litter or dead twigs ¼ inch or less in diameter must be reasonably dry (15 percent moisture content or less) for reliable predictions. Usually this will be reached with 5 consecutive days of seasonably warm weather, April through October, and with 10 days during the rest of the year.

- Winter rainfall records representative of the area for which the ROS values are desired (past wildfires, going wildfires, or prescribed burns) must be available. These records make it possible to select one of the three following climatological conditions that best describe past winter rainfall:

Condition 1—$\geq$ 3.00 inches of precipitation preceding December + January.

Condition 2—< 3.00 inches of precipitation preceding December + January. Precipitation February + March <3.00 inches.

Condition 3—< 3.00 inches of precipitation preceding December + January. Precipitation February + March $\geq$ 3.00 inches.

- The burning experiments on which the model was based were conducted in pure shrub live oak (*Quercus turbinella* Greene), and oak leaves were used for determining leaf moisture content.
- Slope was *not* included as a factor in the model because the experimental burns were conducted on essentially flat terrain. (Obviously the fire manager would not ignore slope as a factor in predicting ROS; because the interactions of slope and wind with fuel are complex, he will have to use his best judgment in "accounting" for slope as he attempts to interpret the meaning of his predicted ROS value.)
- Rate of Spread is expressed in terms of feet per minute—forward spread with the wind, or radial spread with no wind.

What You Need—How You Get It

An almost unlimited number of variables or factors could be measured or considered in developing a model to predict ROS. Most of these variables fall in one of the following categories: climatological data (past weather records), current weather factors, or fuel characteristics (chemistry, loading, and moisture). The variables selected—those that you will need to plug into the formula—are described below.

Leaf moisture content (percent).—Expressed in terms of ovendry weight, this variable can be measured directly if you have the proper facilities, *or,* more conveniently, leaf moisture content can be estimated from *table 1.*

Air temperature (°F).—Easily measured. The dry bulb on a sling psychrometer will do. The observed value is not used directly in the formula, however; *table 2* is used to transform the actual temperature to the value to be entered in the formula. Measure on site if possible.

Relative humidity (percent).—May be accurately measured with a sling or fan psychrometer. Measure on site if possible. *Table 3* must be used to get a converted value for use in the ROS equation. For reconstructing ROS on *past fires,* humidities (and temperatures) could be read from an accurately adjusted hygrothermograph.

Net solar radiation (langleys/minute).—Can be measured directly with appropriate instrument, but a very good estimate may be made from *figure 1.*

On a *clear* day, use your judgment to select a value between the maximum and minimum values; on cloudy days, use cloudy day curve.

Figure 1 shows midday values. For time before and after midday, correct by multiplying the selected value from *figure 1* by the factor found in *table 4.* With this value, go to *table 5* to get the transformed radiation value.

Windspeed (miles/hour).—Easily measured with hand-held or tower-mounted wind instruments. Adhere to standard 20-foot-high anemometer exposure if possible. Record directly. Measure on site if possible.

Chemical coefficient.—This variable accounts for the phosphorus content of the leaves which affects their flammability. Use *table 6* to determine the value to be entered in the formula.

A "computation worksheet" with sample calculations (see fig. 2) is provided in the "How To Use It" section that shows input variables *measured,* needed *transformations,* standard *coefficients,* and equation *terms.* A blank form that may be reproduced for field use appears on the inside back cover.

How To Use It

Once the measured and transformed values are entered on the worksheet and the mathematical coefficient is applied to yield the equation term, it is a relatively simple task to determine the ROS. The ROS equation, a sample problem, and the steps for solving it, are listed below. The equation shows the *constant values* and *variables* that are measured or determined from tables. The sample problem is worked out by following the appropriate steps on a worksheet (fig. 2).

Table 1.--Leaf moisture content (M) values for approximating ROS under three conditions

Month	Condition 1	Condition 2	Condition 3	Definition
		Percent		
March	79	79	79	Condition 1: ≥3.00 inches of precipitation preceding December + January.
April	82	76	81	
May	134	74	82	
June	96	73	89	Condition 2: <3.00 inches of precipitation preceding December + January. Precipitation February + March <3.00 inches.
July	86	70	79	
August	86	105	93	
September	81	99	88	
October	80	89	84	
November	81	88	81	Condition 3: <3.00 inches of precipitation preceding December + January. Precipitation February + March ≥3.00 inches.
December	81	86	81	
January	77	85	77	
February	78	84	78	

Table 2.--Transformation of air temperatures

Measured air temperature	0	1	2	3	4	5	6 ↓	7	8	9
4	20.0	20.8	21.5	22.0	22.8	23.4	24.5	25.5	26.5	27.7
5	28.5	30.0	31.5	33.0	34.5	36.0	38.0	39.5	41.5	43.5
6	46.0	48.5	51.3	54.0	57.0	61.0	65.7	70.3	74.5	78.8
7	83.0	86.3	89.5	91.5	93.0	94.5	95.5	96.5	97.0	97.5
8 →	98.0	98.2	98.4	98.6	98.8	99.0	99.0	99.0	99.1	99.1
9	99.1	99.2	99.2	99.3	99.4	99.5	99.5	99.6	99.7	99.7
10	99.8	99.8	99.8	99.9	99.9	99.9	99.9	99.9	100.0	100.0
11	100.0									

Example: 86° = 99.0 transformed

Table 3.--Transformation of relative humidity

Measured relative humidity	0 ↓	1	2	3	4	5	6	7	8	9
0					4.5	4.6	4.7	4.8	5.0	5.1
1	5.5	6.0	6.5	7.5	8.7	10.2	11.8	13.5	15.5	18.0
2 →	20.5	23.0	25.2	28.0	30.0	32.0	34.0	36.0	37.8	39.5
3	40.5	41.5	42.5	43.5	44.2	45.0	45.6	46.2	47.0	47.5
4	48.0	48.4	48.8	49.2	49.6	50.0	50.5	50.9	51.3	51.7
5	52.0	52.2	52.4	52.6	52.8	53.0	53.2	53.5	53.7	53.9
6	54.0	54.1	54.2	54.3	54.4	54.5	54.6	54.7	54.8	54.9
7	55.0									

Example: 20% = 20.5 transformed

Table 4.--Net solar radiation correction for time of day

Month	Time of day								
	8	9	10	11	12	13	14	15	16
Apr.-Sept.	0.31	0.48	0.76	0.93	0.98	1.00	0.94	0.83	0.32
Oct.-Mar.	.00	.25	.64	.89	.99	.99	.79	.47	.00

Figure 1.—Midday radiation values. Near sources of significant pollution, net radiation would be lower. The aberrations in the May-June period apparently result from atmospheric haze associated with drought and turbulence.

Table 5.--Transformation of solar radiation

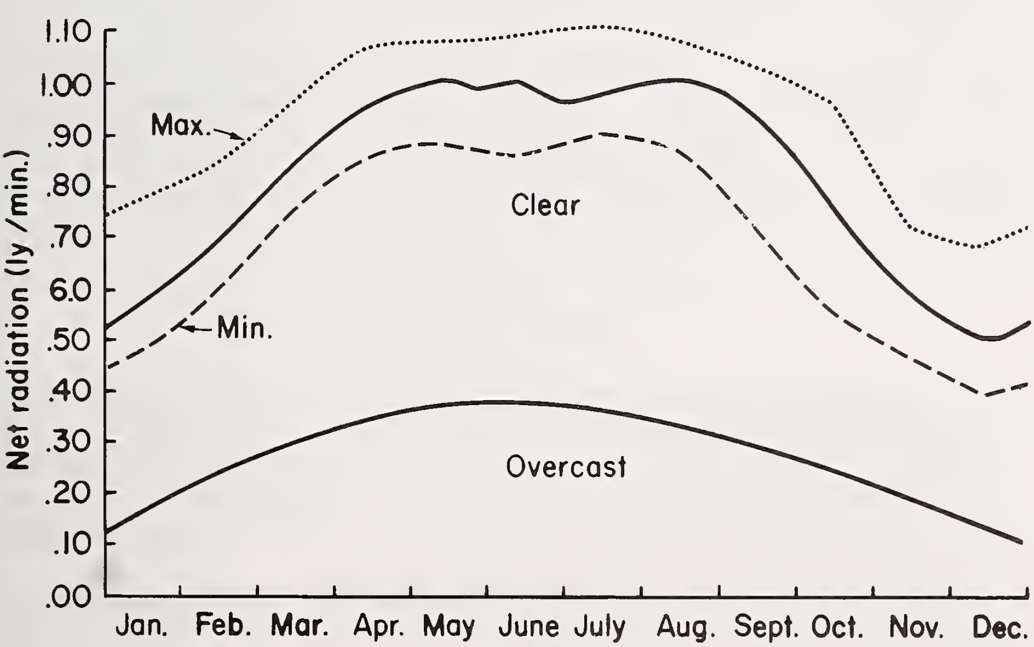
Measured net solar radiation	0	1	2	3	4	5	6	7	8	9
.2									.150	.170
.3	.185	.205	.220	.240	.255	.270	.290	.310	.325	.340
.4	.355	.370	.388	.404	.415	.431	.488	.464	.480	.495
.5	.510	.525	.540	.553	.566	.580	.595	.609	.623	.636
.6	.650	.663	.679	.693	.707	.720	.733	.745	.757	.768
.7	.780	.790	.800	.810	.820	.830	.839	.848	.856	.865
.8	.873	.881	.888	.896	.904	.910	.915	.920	.926	.932
.9	.936	.940	.943	.945	.948	.950	.952	.954	.956	.958
1.0	.960	.960	.960	.960	.960	.960	.960	.960	.960	.960
1.1	.960									

Example: 1.07 = .96 transformed

Table 6.--Chemical coefficient to correct for foliar phosphorus content under three conditions[1]

Month	Condition 1	Condition 2	Condition 3	Month	Condition 1	Condition 2	Condition 3
	Percent				*Percent*		
March	1.0	2.2	2.2	August	1.7	1.0	1.0
April	1.0	1.6	1.6 (early)	September	1.0	1.0	1.0
			1.0 (late)	October	1.0	1.0	1.0
May	1.0	1.6	1.0 (early)	November	1.0	1.0	1.0
			1.6 (late)	December	1.0	1.0	1.0
June	1.0	1.7	1.7	January	1.0	1.7	1.7
July	1.6	1.6	1.0	February	1.0	1.8	1.8

[1]Conditions as defined in table 1.



The Equation

$$\text{ROS (ft/min)} = (10.0 - 0.040\,M + 0.059\,T - 0.121\,H + 6.48\,r + 0.301\,W)\,CC$$

where
M = leaf moisture content (%)
T = air temperature (°F)
H = relative humidity (%)
r = net solar radiation (ly/min)
W = windspeed (m/h)
CC = chemical coefficient

Sample Problem

Assume: Condition 1, 1300 hours, clear, August weather. These criteria indicate a Leaf Moisture Content (M) of 86%. The air temperature (T) is measured as 86°F; relative humidity (H) as 20 percent; and windspeed (W) as 4 miles per hour. Net solar radiation (r), as determined from the "maximum" curve in figure 1, is 1.07 ly/min. Chemical coefficient (CC) from table 6 is 1.7.

Steps for Solving the Equation

Step 1.—Enter the estimated or measured input variables on the worksheet.

Step 2.—List the transformed numbers from tables 1 through 6 and figure 1 alongside the estimated or measured column from step 1.

Step 3.—Multiply the numbers in step 1 (or step 2 if transformed) by appropriate *coefficient* from the equation.

Step 4.—*Add* the terms computed in step 3, keeping signs straight. (*Don't forget to add the constant term, 10.0*).

Step 5.—Multiply answer from step 4 by chemical coefficient to get estimated ROS.

The *estimated* or *measured values, transformed values, standard coefficients,* and *equation terms* are shown on the sample worksheet. The predicted ROS value of 29.48 (rounded off to 29), is your final answer *based on the formula.* As mentioned earlier, this value must be tempered with *judgment* and *experience* when predicting the behavior of a wildfire or a planned prescribed fire.

What It Means

Predictions with this ROS model were compared with actual ROS on four small evaluation fires. Spread was measured both within clumps and between a number of clumps across breaks of varying widths. This small sample indicates that fires in broken, discontinuous fuel spread about 5 percent slower, on an average, than fires in continuous, relatively homogeneous fuel.

How can statistical ROS predictions be interpreted by the fire manager?— Key ROS numbers are 10, 20, and 40 for *level* or *slightly sloping* areas.

Location: Mingus
Date: 8/10/75
Hour: 1300

Rate of Spread

Computation Worksheet

Line	Input variables			Standard coefficients	Equation term
		Estimated or measured	Transformed		
1.	Constant			→	+ 10.0
2.	Leaf moisture content, M (%) (*table 1*)	86	—	x (-0.040)	= - 3.44
3.	Air temperature, T (°F) (*table 2*)	86	99	x (+0.059)	= + 5.84
4.	Relative humidity, H (%) (*table 3*)	20	20.5	x (-0.121)	= - 2.48
5.	Net solar radiation, r (ly/min) (*fig. 1*)	1.07	—		
6.	Time-of-day correction (*table 4*)	1.00	—		
7.	Line 5 x line 6 = (. . . *and table 5*)	1.07	.96	x (+6.48)	= + 6.22
8.	Windspeed (m/h)	4	—	x (+0.301)	= + 1.20
9.	Total			→	17.34
10.	Chemical coefficient (*table 6*)	—	1.7		
11.	ROS (ft/min) (line 9 x line 10) =			→	29.48

Figure 2.—Sample calculations on computation worksheet, showing the input variables, transformations, standard coefficients, and equation terms used to determine rate of spread (ROS).

When predicted ROS is less than 10 (approximately), fire probably will not spread well. Fire set repeatedly may spread through the litter and consume some aerial fuels, but normally will not crown continuously through an individual clump or spread from clump to clump.

Between 10 and 20 (approximately), individually ignited clumps probably will burn reasonably well, but fire normally will not spread from clump to clump continuously.

Above 20, fire normally will spread from clump to clump continuously, and up to 40 will burn steadily, but not explosively.

Above 40 (approximately), fires will probably burn intensely, spread rapidly, and conditions will probably be too severe for most prescribed burning.

General.—People experienced with fire characteristics in Arizona oak chaparral have always maintained that chaparral either burns fiercely or does not burn at all—no graduation in between. This rule of thumb is relatively accurate. The critical ROS threshold is around 20 feet per minute; conditions must be suitable for generating spread at or above that rate before fire will spread across country. Thus the minimum sustained spread (without spotting) ever seen, usually in intentional fire, is about one-quarter mile per hour; in wildfires, normally one-half mile per hour or higher because wildfires tend to occur during some of the worst conditions and commonly include spotting.

A 28,400-acre wildfire on the Prescott National Forest, May 14-20, 1972, provided an operational check of the statistical model and interpretations. The initial ROS, from 1215 to 1500 hours in a mixture of oak and manzanita chaparral, was scaled at 45 feet per minute, 1.25 feet per minute less than the fastest spreading research fire. The wildfire included some short-range spotting and a variety of slopes and fuel conditions. Predicted ROS was 40 feet per minute (based on data from the tables, and measured temperature, relative humidity, and wind). This small difference (45 vs. 40 feet per minute) probably is attributable to spotting, favorable slope-wind interaction during part of the run, and the admixture of manzanita.

The type of fire that does not spread from clump to clump is potentially quite useful in land management. It can be used to burn firebreaks and small areas safely without bulldozing, brush smashing, or other special measures heretofore employed in intentional burning, at considerable cost both in dollars and site disturbance. Forming fuelbreaks by nonspreading fire is feasible, economical, and effective, although additional research is needed to work out operational details. When designed to dissect large areas of chaparral, these breaks can substantially lessen the probability of large, catastrophic wildfires.

Agriculture—CSU, Fort Collins

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Location: ____________

Date: ____________

Hour: ____________

Rate of Spread

Computation Worksheet

Line	Input variables	Estimated or measured	Transformed	Standard coefficients	Equation term
1.	Constant →				+ 10.0
2.	Leaf moisture content, M (%) (*table 1*)	______	—	x (-0.040)	= - ______
3.	Air temperature, T (°F) (*table 2*)	______	______	x (+0.059)	= + ______
4.	Relative humidity, H (%) (*table 3*)	______	______	x (-0.121)	= - ______
5.	Net solar radiation, r (ly/min) (*fig. 1*)	______	—		
6.	Time-of-day correction (*table 4*)	______	—		
7.	Line 5 x line 6 = (. . . *and table 5*)	______	______	x (+6.48)	= + ______
8.	Windspeed (m/h)	______	—	x (+0.301)	= + ______
9.	Total →				______
10.	Chemical coefficient (*table 6*)	—	______		
11.	ROS (ft/min) (line 9 x line 10) = →				______

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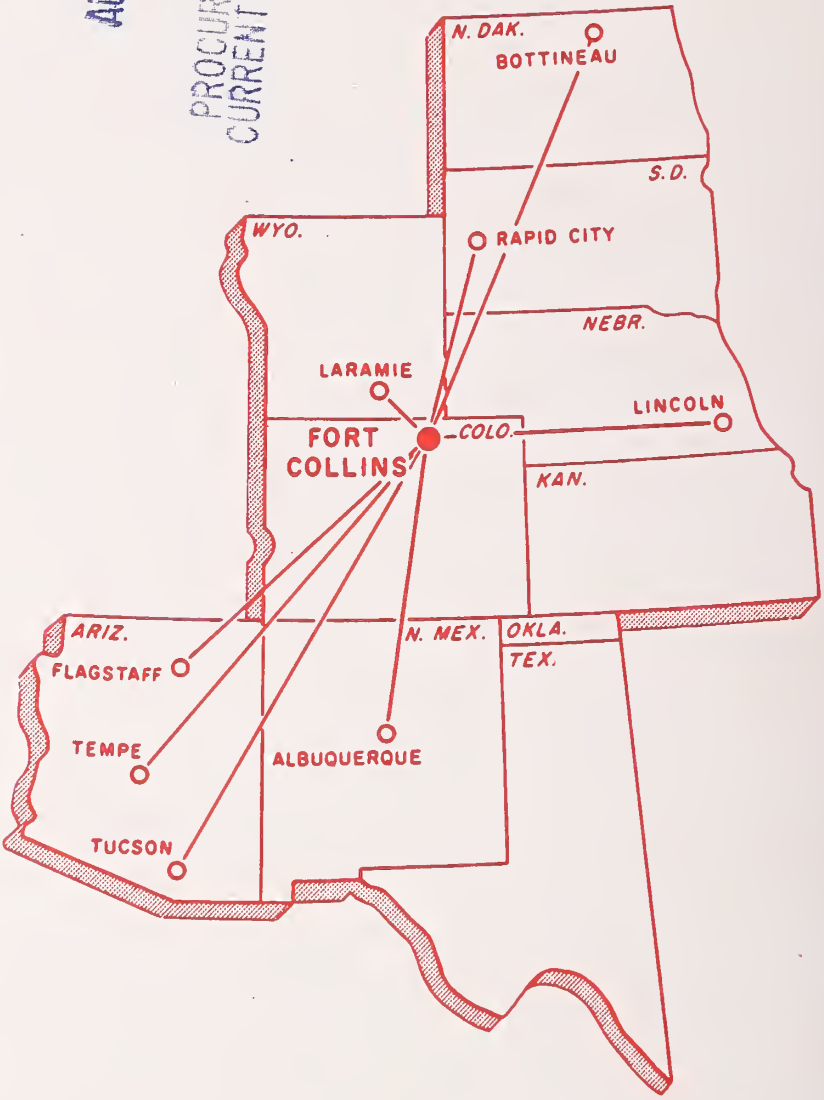
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